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Study the Gap Wind in the Sepeed-Rood Valley of Iran Using a Hydraulic Model

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Abstract: The aim of this study was to apply a hydraulic model for the gap flow in the Sepeed Rood valley to assess the roles of factors such as sea breeze affecting the flow in the gap. The valley is considered as a narrow passage in Alborz mountain range in which the remarkable air flow causes intensive winds in its route cities such as Rood Bar and Manjil. Since the gap winds are considered as the condensed air flow in low levels which are horizontally limited by the channel rims and vertically by temperature inversion, it is similar to the flow in a channel and the hydraulic model can be applied for it. The application of scale analysis indicates the strength of F_0 term related to the contribution of heat forcing circulation such as sea breeze which plays a role for creating the winds with the average daily velocity much bigger than the night most especially in summer days. Moreover it indicates the validity of Bernoulli equation application in winter most especially when the regional circulations are weak and synoptic forcing is the dominant factor in the gap wind, while in summer the effects of regional circulations such as sea breeze are more noticeable.

Key words: Gap wind, sea breeze, Bernoulli equation, pressure gradient

INTRODUCTION

The interaction between the regional or mesoscale pressure gradient and the environment topography can cause intensive winds in many mountainous areas. Some mountains separate different air masses and in these cases, the strong pressure gradient in the width of mountains accelerates the air masses through the existing gaps creating strong non geostrophic winds known as gap winds. Sepeed- Rood River valley located in north of Iran is in the form of a deep gap in Alborz Mountain range in which the existing pressure gradient of the two mountain sides leads to blowing of strong winds with the velocity of 8-18 m sec^{-1} and sometimes even up to 30 m sec^{-1}. The observed 15°C deviation of the gap from the north direction is shown in Fig. 2 which is dominant. Figure 2 indicates the direction changes proportional to the pressure difference in the two ends of the gap during the years 1996-1999.

The first attempts to describe gap winds are found in (Lackmann and Overland, 1817; Reed, 1939; Tyson and White, 1972; Marvill and Jayaweera, 1975; Ryan, 1977; Dantels and Schroeder, 1978; Ramachandran *et al*., 1980; Banta and Cotton, 1981).

Reed (1939) observed the non geostrophic nature of the gap wind in Juan de Fuca Bay and examined the synoptic conditions which are associated with it. The gap wind was introduced as a flow of somehow homogenous air in a sea surface channel which can be accelerated by the pressure gradient component parallel to the channel axis.

Ramachandran *et al*. (1980) performed an observational study to explain the downwind increase of winds transiting in a gap in India. Observed data reveals a fanning out of surface winds passing

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through the gap. Gap winds in Howe Sound, British Columbia are described by Jackson and Steyn (1994a, b). Surface and vertical sounding measurements show that gap winds vary along and across the channel, as well as vertically. Mass *et al*. (1995) studied localized windstorm suffering some northwest areas of Washington State. The study showed that the arctic air originated in British Columbia is descended into a mesoscale gap in the Coast/Cascade Mountains. They describe this gap acceleration by a three way balance among the pressure gradient force, friction and inertia.

Liu *et al*. (2000) used a Navy's Coupled Ocean-Atmosphere Mesosclae model to study a flow in the Lut Valley, Iran. They explained the flow is originated as a gap flow in the convergence topography of the Lut valley by the valley parallel pressure gradients produced as a result of the large scale processes and by the pressure of cold air over the valley's sloping terrain. Olson *et al*. (2007) compared two Coastal Barrier Jet Events along the Southeast Alaskan Coast with high-resolution simulations from the first intensive observation period (IOP1). Romero-Centeno *et al*. (2007) studied intraseasonal wind variability over the northeastern tropical Pacific (NETP), its relationship with other variables and the connection with large- and middle-scale atmospheric patterns were analyzed by using a suite of datasets. The SLP pattern causing the gap winds in winter is different than in midsummer, being the southeastward intrusion of high pressure systems coming from the northwest, the main cause of the large meridional SLP gradients in Tehuantepec and the western Caribbean.

The aim of this study was to use the Bernoulli equation to compute wind velocity through the valley and assess the role of external factors such as sea breeze which is most dominant during summer.

MATERIALS AND METHODS

Study Area and Measurements

The Sepeed-Rood gap is a narrow break in the Albobrz mountain range with the length of 55 km, width of 7 km and the depth of 1800 m (Fig. 1). The Sepeed-Rood gap is a narrow break in the Albobrz mountain range with the length of 55 km, width of 7 km and the depth of 1800 m (Fig. 1). In this study the meteorological data including air temperature, air pressure and wind velocity measured by the Rasht station in the north of valley with humid and rainy climate through the year and the Manjil station in the south of valley with rainy winter and dry summer generally with semi-arid climate conditions were analyzed for the period of four years from 1996 to 1999.

Geographical and climatic attribute of the stations are reported in Table 1. The Rasht station located in the north of Alborz chain has very humid and rainy climate through the year while the Manjil station have rainy winter and dry summer generally with semi-arid climate conditions.

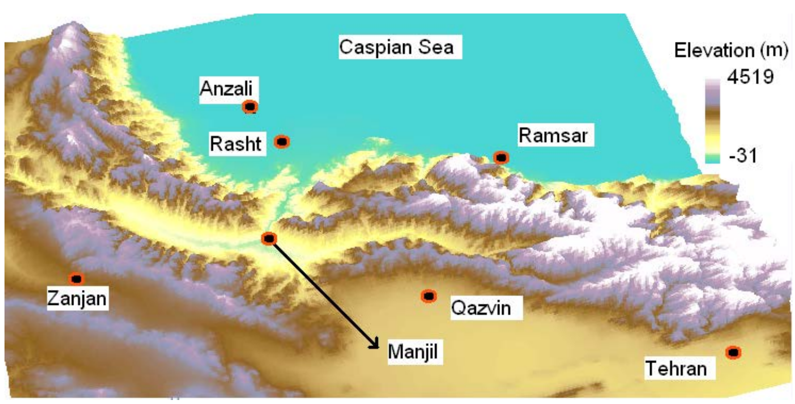

Fig. 1: 3D view of the study area. Manjil station in located in the valley

Table 1: Geographical and climatic attributes of the studied stations

Station	Latitude (°N)	Longitude (°E)	Elevation (m)	T_{max} (°C)	T_{min} (°C)	Rain (mm)	Win speed knot
Ramsar	36.9	50.666667	-20.0	19.4	12.6	1218.0	3.2
Rasht	37.25	49.6	-6.9	20.6	11.3	1359.0	2.5
Anzali	37.46667	49.466667	-26.2	19.2	13.2	1854.0	3.9
Manjil	36.73333	49.4	333.0	22.4	12.7	209.3	12.1
Tehran	35.68333	51.316667	1190.8	22.6	11.8	231.0	5.2
Qazvin	36.25	50.05	1279.2	21.2	6.9	316.0	3.9
Zanjan	36.68333	48.483333	1663.0	18.0	4.0	313.0	3.7

Methodology

In order to obtain the momentum equation, the gap flow is considered as two non compressed layers, a low condensed and stagnant fluid ρ_2 on top and a more condensed fluid ρ_1 with a low depth h at the bottom. By taking the narrowness of gap into consideration, the components of the gap wind velocity would be small in width and perpendiculars. So, the momentum equation along the gap would be as follow:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}-f\upsilon+g'\frac{dh}{dx}+g'\frac{de}{dx}+\frac{1}{\rho_1}\frac{dp}{dx}-\frac{1}{\rho_1}\frac{d\tau}{dz}=0$$
$$g'=\frac{g(\rho_1-\rho_2)}{\rho_1}=\frac{g(\theta_2-\theta_1)}{\theta_1} \quad (1)$$

where, u is wind velocity, f is, υ is , ǵ is buoyancy, e the channel height, P is the pressure, τ is eddy correlation, t is time, x is the distance in north-south direction, z is the depth of gap wind, g is the gravity constant, θ_1 is the average potential temperature of a bottom mixing layer and θ_2 is the average potential temperature of the top temperature inversion layer.

The first term indicates the local velocity, the second is the velocity advection, the third is Corriolis force, the fourth is the horizontal pressure gradient derived from the gradient in the thickness of a condensed air, the fifth is the horizontal pressure gradient force as a result of the changes in the channel height, the sixth is the external pressure gradient force and the last one is the friction which can be written as below:

$$\frac{1}{\rho_1}\frac{d\tau}{dz}=k\frac{\partial^2 u}{\partial^2 z} \quad (2)$$

where, k is the momentum eddy transfer coefficient. Liu *et al*. (2000) defined the fourth and fifth terms of the Eq. 1 as follows:

$$g'\frac{de}{dx}\approx g\frac{\Delta\theta}{\theta}\sin\alpha$$
$$g'\frac{dh}{dx}\approx g\frac{\Delta\theta}{\theta}\cos\alpha \quad (3)$$

where, $\Delta\theta$ is the difference between the mixing layer potential temperature and the temperature inversion layer while θ is the average potential temperature in the bottom layer. Liu *et al*. (2000) combined Eq. 2 with external pressure gradient term and proposed the following equation to estimate the total pressure gradient:

$$PG_{total}=PG_{1arge}+PG_{slope}+PG_{depth}+PG_{sb} \quad (4)$$

where, PG_{total} is the pressure gradient along the gap. The large scale pressure gradient is as a result of high pressure on the Caspian Sea or at the bottom of the Alborz Mountains. The second term is as a result of sheared and stable airflow under the ground gradient and the third term derived from the gap flow layer depth changes along its axis. PG_{sb} is the pressure gradient related to sea-land temperature contrast, however during the day especially in the afternoons this term makes a strong contribution. At night PG_{depth} plays a stronger role in the total pressure gradient since the cold layer becomes deeper and its gravity effect increases. When the new day starts the cold weather of the valley would have static stability decreasing as a result of the turbulent mixing of daily heating which leads to a little penetration of the temperature inversion layer into the gap wind depth. In this regard PG_{depth} becomes small.

Term PG_{slope} always plays a role in the total pressure gradient but it will increase at night as a result of daily changes in the cold air static stability. We can add the role of heat circulations as one of the effective factors on Sepid Roud gap flow with the F_0 term which no relation has been obtained for it yet. By taking the observation of Sepid Roud gap wind velocity into consideration which is in Fig. 2, it can be understood that the effect of F_0 term during summer days is strong enough to create the winds with the average daily velocity much bigger than the night one.

Equation 1 scale analysis is done by taking the amounts of dimensional parameters for mesoscale motions into consideration which are:

$$\rho \sim 1\,\text{kg m}^{-3},\ \Delta p \sim 10^2\,\text{pa}, f \sim 10^{-4}\text{s}^{-1}, H \sim 10^3\ \text{m}, L \sim 10^4\text{m},$$
$$t \sim 10^4\text{s}, u \sim 10\ \text{m.s}^{-1}, \theta \sim 10^2\text{K}, k \sim 10\ \text{m}^2\text{s}^{-1}$$

Moreover the average Manjil to Rasht slope is considered as Sepid Roud gap slope, so the amount of α is calculated as 0.3°. By substituting these amounts in an equation, the magnitude of each sentence would be obtained. By having a comparison between the values of the equation sentences it seems the balance between the three sentences of advection, external pressure gradient and heat circulation or some how Faun reveals the current existence and intensity in Sepid Roud valley:

$$u\left(\frac{\partial u}{\partial x}\right) \approx -\frac{1}{\rho}\left(\frac{\partial p}{\partial x}\right) + F_0 \tag{5}$$

In case of not considering F_0, the Bernoulli equation would be as below:

$$\frac{u^2}{2} = \frac{u_0^2}{2} - \frac{\Delta p}{\rho} \tag{6}$$

where, u_0 is the primitive velocity in the gap entrance and Äp is the gap two sides pressure gradient. So, Manjil wind velocity could be calculated by the below relation where u_2 is Manjil wind velocity, p_2 Manjil pressure, u_1 Rasht wind velocity and p_1 Rasht pressure:

$$u_2^2 = \frac{1}{\rho}(p_1 - p_2) + u_1^2 \tag{7}$$

There are some limitations bout Eq. 6, which could be explained as non existence of accurate wind records in flow convergence Zone (u_1) and non existence of accurate measuring about the real length of the gap respectively.

We solve the Bernoulli equation for the condition that the Rasht station pressure is considered as the gap entrance pressure and the Manjil station as the gap exit pressure. In order to obtain the flow velocity in a gap entrance, we assume the velocity vector follow the linear growth from the coast to the gap entrance. In this regard the velocity coordinate of the Rasht station which is align with the gap entrance is multiplied to a constant value such as ë and is assumed as the flow velocity in a gap entrance.

Calculations indicate that in order to have convergence for wind in the gap entrance, the precise wind direction is 337.5° in the Rasht station.

Calculations indicate by considering $\lambda = 6.05$ the velocity values obtained by Bernoulli equation is in accordance with the observed velocities in the station.

In the scale analysis method we separate the large terms and will omit the rest. So, the Bernoulli Equation would be as Eq. 5.

RESULTS

Figure 2 refers to the Bernoulli equation graph for Sepid Roud gap in summer 1999 while Fig. 3 indicates the observational values for Manjil-Rasht difference vs. time in summer 1999. Since in a gap flow the velocity component along Z axis (towards up) and Y axis (in the direction of width of the gap) are zero, the flow is completely in a channel form and the hydraulic model can be applied for it.

By combining the friction term with external pressure gradient term in the momentum equation the total pressure gradient along the gap can be written as a result of four terms which are the large scale pressure gradient as a consequence of high pressure on the Caspian Sea or at the bottom of the Alborz Mountains. PG_{slope} is as a result of sheared and stable airflow under the ground gradient and the PG_{depth} derived from the gap flow layer depth changes along its axis. PG_{sb} is the pressure gradient related to sea-land temperature contrast, however during the summer days especially in the afternoons this term makes a strong contribution in the total pressure gradient along the gap. By taking the observation of Sepid Roud gap wind velocity into consideration which is in Fig. 2 and scale analysis, it can be understood that the effect of F_0 term during summer days is strong enough to create the winds with the average daily velocity much bigger than the night one. Regarding the pressure gradient related

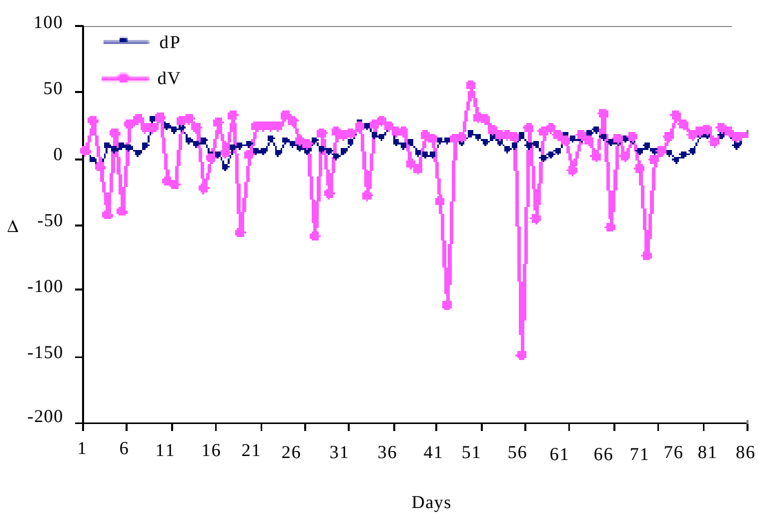

Fig. 2: Bernoulli equation graph for Sepid Roud gap in summer 1999

Table 2: The magnitude of F_0 as a result of heat forcing circulations such as Sea breeze and External factors such as Fohn is obtained as 10^{-2}

		Gravitational wava effect					
Name of terms	Eddy correlation	Pressure gradient as a Result of depth of flow in a gap	Pressure gradient as a result of gap slopness	Synoptic pressure gradient	Carioles force	Flow advection along the gap velocity	Ocal intensity of gap wind
Related formula	$k\left(\frac{\partial^2 U}{\partial z^2}\right)$	$g'\left(\frac{dh}{dx}\right)$	$g'\left(\frac{de}{dx}\right)$	$\frac{1}{\rho}\left(\frac{\partial P}{\partial x}\right)$	fv	$u\frac{\partial U}{\partial x}$	$\frac{\partial U}{\partial t}$
Scale analysis	$k\left(\frac{U}{\ell^2}\right)$	$g\left(\frac{\Delta\theta}{\theta}\right)\times\cos(\alpha)$	$g\left(\frac{\Delta\theta}{\theta}\right)\times\sin(\alpha)$	$\frac{1}{\rho}\left(\frac{\Delta P}{L}\right)$	fU	$\frac{U^2}{L}$	$\frac{U}{t}$
Magnitude	10^{-4}	10^{-3}	10^{-43}	10^{-2}	10^{-3}	10^{-2}	10^{-3}

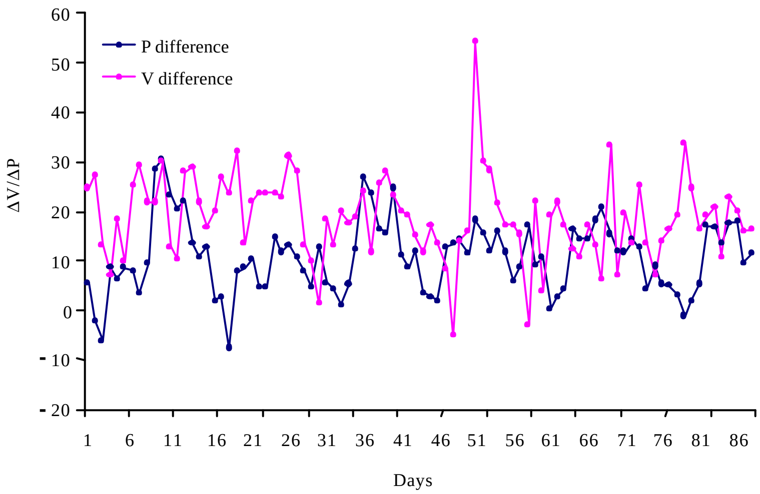

Fig. 3: The observational values for Manjil-Rasht difference versus time (summer 1999)

to sea-land temperature contrast during the summer days especially in the afternoons which leads to the strong contribution of remarkable velocities formation, the difference between Fig. 2 (referring to the Bernoulli equation graph for Sepid Roud gap in summer 1999) and Fig. 3 (indicating the observational values for Manjil-Rasht difference vs. time in summer 1999) could be considered as a result of heat forcing circulations such as Sea breeze and External factors such as Fohn.

The results of scale analysis of all the terms of Eq. 1 which are shown in Table 2 could be applied for the estimation of Eq. 1.

We omit F_0 in the scale analysis to obtain the magnitude of Sea breeze values by this method. The F_0 magnitude which is due to heat forcing circulations such as Sea breeze and External factors such as Fohn is estimated as 10^{-2} by the comparison between Eq. 1 and 4.

CONCLUSIONS

In this study the meteorological data including air temperature, air pressure and wind velocity measured by the Rasht station in the north of valley and the Manjil station in the south of valley were analyzed for the period of four years from1996-1999. The gap winds are assumed to be the condensed air flow in low levels horizontally limited by the channel rims and vertically by temperature inversion.

In this regard it is similar to the flow in a channel. Since in a gap flow the velocity Component along Z axis (towards up) and Y axis (in the direction of width of the gap) are zero, the flow is completely in a channel form and the hydraulic model can be applied for it. By using the Bernoulli equation for the computation of wind velocities a difference between the computational and observational wind velocities values is noticed in summer days, while in winter as a result of the weakness of local circulations and heat forgings such as sea breeze in this season, the flow in a gap follow the Bernoulli Equation. Moreover scale analysis indicate magnitude of F_0 referring to heat forcing circulations such as Sea breeze and External factors such as Fohn is obtained as 10^{-2} in summer. PG_{sb} is the pressure gradient related to sea-land temperature contrast, however during the summer days especially in the afternoons this term makes a strong contribution in the total pressure gradient along the gap. It is demonstrated that the Sea breeze sometimes causes the blowing of intensive northerly winds while it occasionally causes the developing of weak southerly winds as a result of negative pressure slope of the valley however sensitivity studies are required in the future.

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